III. Biopotential Electrodes and Chemical Sensors

Electrodes Electrolyte Interface, Half-Cell Potential, Polarization, Polarizable and Non Polarizable, Electrodes, Reference Electrode, Hydrogen Electrode, Electrode Skin-Interface and Motion Artifact. Surface Electrodes. Oxygen electrodes, CO_2 electrodes, enzyme electrode, construction, ISFET for glucose, urea etc. fiber optic sensors.

3.1 Biopotential Electrodes

- Electrodes that are capable of picking up the electrical signals of the body are called as biopotential electrodes.
- Signals are developed due to chemical activity in the cells/ biological system.
- Chemical activity is brought about by Na+, K+ and Cl- ions concentration gradient and unbalanced conditions lead to chemical activity in the human body.
- Current flows in the measuring circuit for at least a fraction of the period of time over which the measurement is made.
- Bioelectric potential generated in the body are ionic potential.
- Electrode carries out a transducing function, because current is
- carried in the body by ions, whereas it is carried in the electrode
- and its lead wire by electrons.
- A transducer that convert the body ionic current in the body into the traditional electronic current flowing in the electrode.
- Able to conduct small current across the interface between the body and the electronic measuring circuit.

3.2 Electrodes-Electrolyte interface

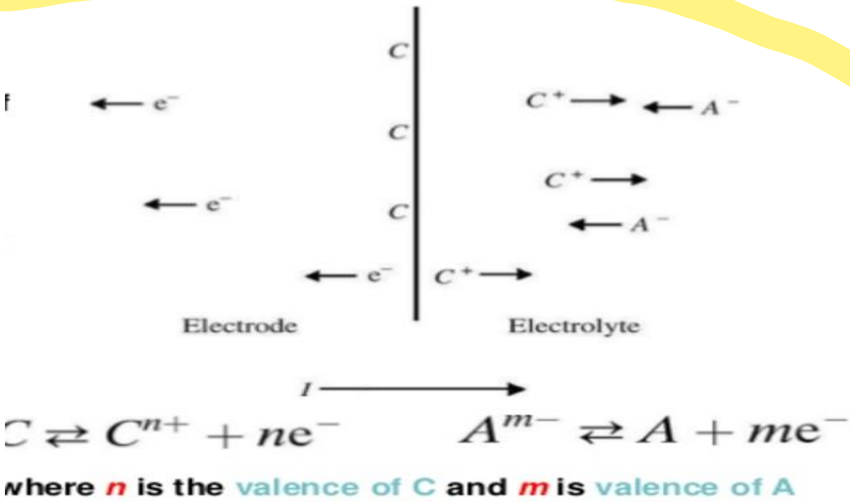


Figure 3.1 Electrodes – Electrolyte interface

A net current (I) that crosses the interface passing from the electrode to electrolyte consists of
1. e- moving in opposite to current in electrode

2. Cations c+ moving in same direction of current

3. Anions A- moving in opposite to current in electrolyte

Electrode consists metallic atomC . Electrolyte consists cations C+ & anions A- .

- The electrode is made up of some atoms of the same material as the cations and that this material in the electrode at the interface can become oxidized to form a cation and one or more free electrons.
- The cation is discharged into the electrolyte; the electron remains as a charge carrier in the electrode.
- These ions are reduced when the process occurs in the reverse direction
- an anion coming to the electrode–electrolyte interface can be oxidized to a neutral atom, giving off one or more free electrons to the electrode.
- Oxidation reaction causes atom to lose electron
- Reduction reaction causes atom to gain electron
- Oxidation is dominant when current flow from electrode to electrolyte and reduction dominate when the current flow is in the opposite.

3.3 Half cell potential

- Voltage developed at electrode-electrolyte interface is called half cell potential or electrode potential.
- In the case of a metal solution interface, an electrode potential results from the difference in rates between two opposing forces
- the passage of ions from the metal into the solution.
- The combination of metallic ions in solution with electrons in the metal to form atoms of the metal.
- So, when a metal electrode comes into contact with an electrolyte (body fluid), there is a tendency for the electrode to discharge ions into solution and for ions in the electrolyte to combine with the electrode.
- The net result is the creation of a charge gradient, the spatial arrangement of which is called the electrical double layer.
- Electrodes in which no net transfer of charge occurs across the metal electrolyte interface is called as perfectly polarised electrodes.
- Electrodes in which unhindered exchange of charge is possible across the metal electrolyte interface are called nonpolarizable electrodes.

3.3 Polarizable and non-polarizable electrodes

Perfectly polarizable electrodes

- Electrodes in which no net transfer of charge occurs across the metal electrolyte interface when a current is applied is called as perfectly polarised electrodes. Example: Platinum Electrode
- The electrode behaves like a capacitor and overpotential is due to concentration.

Non polarizable electrodes

- Electrodes in which current passes freely across the electrode- electrolyte interface are called nonpolarizable electrodes.
- Electrodes in which unhindered exchange of charge is possible across the metal electrolyte interface are called nonpolarizable electrodes.
- Here current flows freely across the interface and energy is not required for it. Example: Ag/AgCl electrode.
- Thus, for perfectly non-polarizable electrodes there are no over-potentials.
- Electrode interface impedance is represented as a resistor.

3.4 Polarization

Half cell potential is altered when there is current flowing in the electrode due to electrode polarization. Overpotential is the difference between the observed half-cell potential with current flow and the equilibrium zero-current half-cell potential.

Mechanism Contributed to overpotential –

Ohmic overpotential: voltage drop along the path of the current, and current changes resistance of electrolyte and thus, a voltage drop does not follow ohm's law.

Concentration overpotential: Current changes the distribution of ions at the electrode-electrolyte interface

Activation overpotential: current changes the rate of oxidation and reduction. Since the activation energy barriers for oxidation and reduction are different, the net activation energy depends on the direction of current and this difference appear as voltage.

$$V_p = V_R + V_c + V_A$$

These three mechanisms of polarization are additive.

Thus the net over-potential of an electrode is given by

$$V_p = E° + V_R + V_c + V_A$$

where Vp = total potential, or polarization potential, of the electrode

$E°$ = half-cell potential

V_R = ohmic overpotential

V_c = concentration overpotential

V_A = activation overpotential

3.5 Resting potential

- In a cell membrane the outside fluid is extra-cellular fluid and inside fluid is intra-cellular fluid.
- The extra-cellular fluid has a large concentration of sodium ions and chloride ions but less concentration of potassium ions.
- The intra-cellular fluid has a high concentration of potassium ions than the sodium ions.
- Cells surrounded by semipermeable membrane permits some substances to pass through and some kept out.
- Cells surrounded by body fluids containing ions.
- Principal ions are (Na+), (K+) and (Cl-).
- When a cell does not send a signal, it is at "resting state".
- Membrane permits the entry of potassium (K+) and chloride (Cl-) ions and stops Sodium ions (Na+).
- sodium ion concentration inside the cell becomes much lower than the outside the cell.
- Inside the cell, potassium and chloride ion concentration is more than the outside the cell.
- Thus the charge balance is not achieved.
- However, an equilibrium is reached with a potential difference across the membrane such that the negative potential on the inside and positive on the outside.
- This membrane potential caused by the different concentration of ions is known as resting potential.
- The cell membrane is negative inside and positive outside.
- The difference in ion concentration results in the Resting Membrane Potential of the cell.
- The value of resting potential is between - 60mV to - 100mV.
- At the resting state, the cell is polarised.

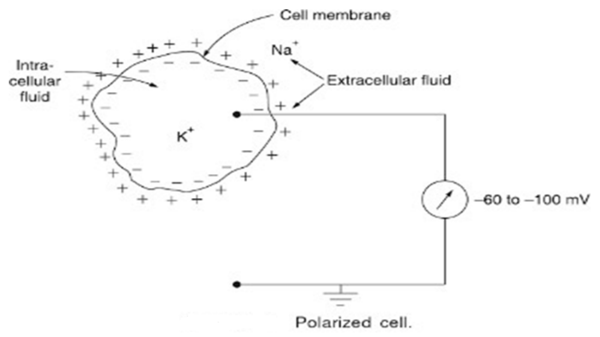


Figure 3.2 Resting potential

3.6 Action potential

- When a section of the cell membrane is excited by some form of applied energy, the permeability of the membrane changes and begins to allow some of the sodium ions to enter.
- Movement of sodium ions into the cell constitutes an ionic current and this reduces the membrane barrier.
- Sodium ions rushes into the cell and try to balance with the ions outside.
- Meanwhile, potassium ions flow outside the cell but unable to move rapidly as sodium ions.
- Thus, the cell has positive potential inside the cell due to the imbalance of potassium ions.
- The positive potential of the cell membrane during excitation is called as action Membrane Potential.
- The value of action potential is 20mV.
- As long as action potential exists, the cell is said to be depolarised.

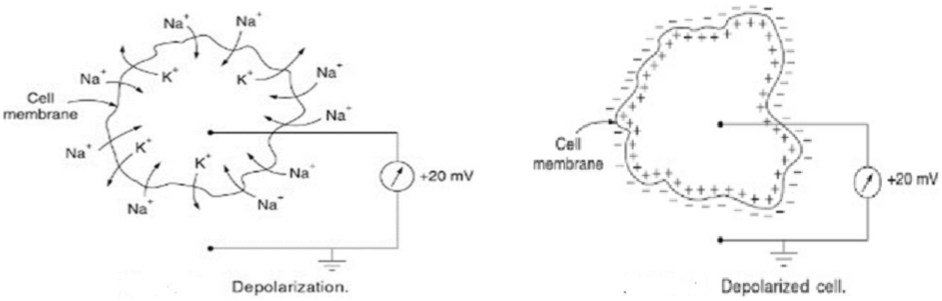


Figure 3.3 Action potential

- Process of changing from resting state to action potential is called as depolarization.
- Once equilibrium is again reached, membrane gets back to semipermeable state and stops entry of sodium ions.
- By a process of sodium pump, all sodium ions are transported outside of the cell and resting potential is attained. This process is called repolarization.

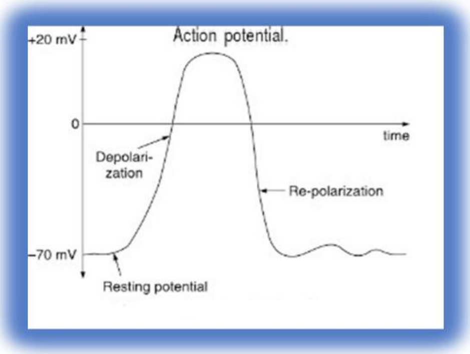


Figure 3.4 Action and resting potential

- All or nothing law- Action potential is always the same for any given cell regardless of the excitation method or intensity of stimulus.
- Absolute refractory period- A brief period of time during which the cell cannot respond to any new stimulus.(1msec in nerve cell)
- Relative refractory period- After Absolute refractory period, during which another action potential can be triggered, but a much more stronger stimulation is required.
- Propagation rate- Rate at which action potential is propagated from cell to cell(conduction velocity or nerve conduction rate).

3.7 Types of electrodes

1.Micro electrodes

- To measure biopotential signals within a single cell
- Metal microelectrode
- Micropipet

2. Depth and needle electrodes

Electrodes penetrate into the skin to record signals. These electrodes are used to measure bio-potential at highly localized extracellular region.

3.Surface electrodes

Measures signal from the surface of the skin

- Metal plate
- Suction cup
- Adhesive tape
- Multipoint
- Floating

4.Chemical electrodes

Measures Ph, pO2, pCo2 of blood

Hydrogen electrode

Reference electrode

Ph, pO2, pCo2 electrode

1.Micro electrode

- Used to measure potential near or within a single cell
- Also called intracellular electrode.
- Small in diameter so that they do not damage cells during insertion.

- Microelectrodes are placed within cell and reference electrodes are placed outside cell.
- Tip diameter range from 0.05 to 10 micrometer
- Two types of micro electrodes
- i) metal micro electrodes
- (ii) micropipet or nonmetal micro electrode

(i)Metal micro electrodes

- These electrodes are made of fine tungsten or stainless steel wire.
- They are formed by electrolytically etching the tip of the tungsten or stainless steel wire to a fine point. This technique is known as electro pointing.
- This etched metal wire is then supported by a larger metallic shaft.
- This metallic shaft acts as a

  - Sturdy mechanical support for the microelectrode.

  -Means of connecting the micro electrode to its lead wire.

- The micro electrode and the supporting shaft is insulated by a polymer material or varnish.
- The extreme tip of the micro electrode is left without insulation.
- The bioelectric potential measured is actually the difference in instantaneous potential of the measuring micro electrode and reference electrode.

Structure of Metal Microelectrode

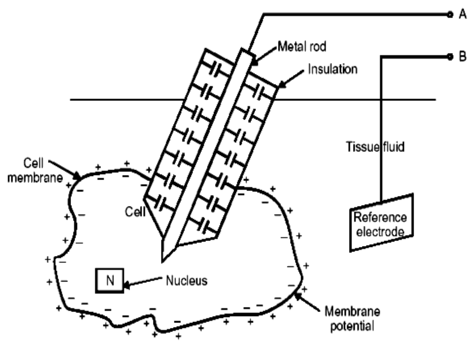


Figure 3.5 Metal micro electrodes

Bioelectric potential is given by,

$E = E_A+E_B+E_C$

E – Bio-potential

E_A – Metal electrode - electrolyte potential at the micro electrode tip

E_B – Reference electrode - electrolyte potential

E_C – Variable cell membrane potential

(ii) Micropipet (or) Non metal electrode

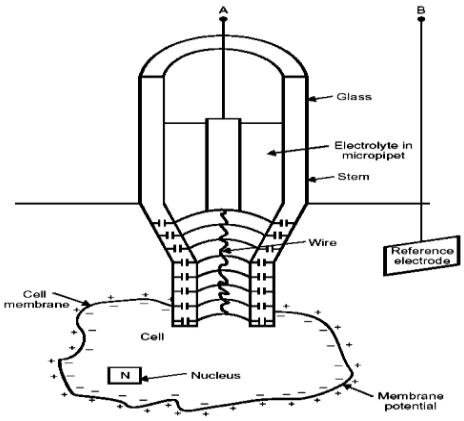


Figure 3.6 Non Metal electrodes

- It consists of a glass Micropipet whose tip's diameter is about 1 micrometer.
- A thin, flexible metal wire made of silver, stainless steel or tungsten is inserted into the stem of the micropipet.
- One end of the metal wire is mounted to a rigid support and the other free end through the stem of the micropipet is resting on the cell to pick up bio-electric potential.
- It is filled with an electrolyte(3 M KCl)
- Here bio-electric potential is given as
- $E = E_A+E_B+E_C+E_D$
- E – Bio-electric Potential
- E_A – Potential between the metal wire and electrolyte filled in the micropipet.
- E_B – Potential between the reference electrode and the extra cellularfluid
- E_C – Variable cell membrane potential
- E_D – Potential existing at the tip due to different electrolytes present in the pipet and the cell.

2.Depth and needle electrodes

- These type of electrodes are used to measure and record bio-electric events from highly localized extra cellular regions.
- They are of two types namely,

i. Depth electrode

ii. Needle electrode

(i)Depth electrode

- Used to study electrical activity of neurons in the superficial layers of the brain.
- Also called as implantable electrodes.
- These are made of a bundle of Teflon insulated platinum 90%- iridium 10% alloy wires
- These wires act as individual electrodes and supported by a stainless steel wire.
- This stainless steel supporting wire is rounded off at the tip for easy insertion into the top layers of the brain.
- The electrode rests on the sub-cortical nerve cells.
- The active area of depth electrode is 0.5 mm^2

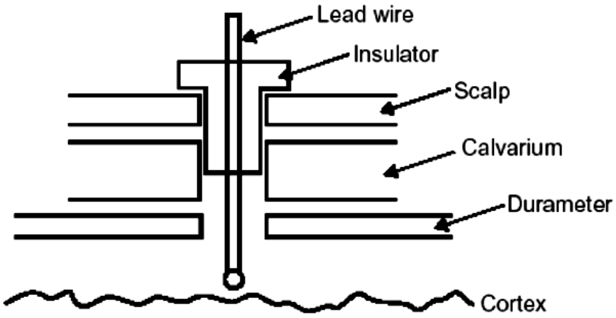


Figure 3.6 Depth electrodes

- The supporting stainless-steel wire can itself act as an electrode if an appropriate varnish is used.
- The supporting wire if made in the form of a capillary tube can be used to inject medicines into the brain.
- Silver sphere cortical surface potential is an example of a implantable depth electrode.
- It has 2mm diameter silver sphere located at tip of cylindrical Teflon insulator through which lead wire passes.
- Calvarium is exposed through incision in scalp.
- Ag sphere introduced and rests on cerebral cortex.

(ii)Needle electrode:

- The needle electrode is used to measure action potentials of peripheral nerves.
- Used to reduce movement artifacts and interface impedance.
- Here a needle is used to make a lumen through which a short length metal wire is inserted.
- This short length metal wire is bent at one end and inserted through the lumen into the muscles.
- This wire picks up the electrical activity of the biological system.
- If one wire is used as a measuring electrode and another separate reference electrode is used then it is called mono-polar needle electrode.
- If two insulated wires are used one as reference and the other as measuring electrode through the lumen of the needle then such an electrode system is called bipolarneedle electrode.

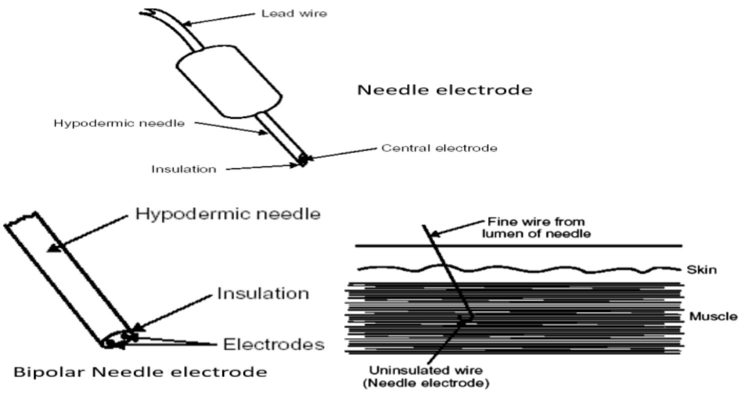


Figure 3.7 Needle electrodes

3.Surface electrodes

- Electrodes used to obtain bioelectric potentials from surface of the body.
- Surface electrodes are used to record ECG, EMG and EEG signals.
- Larger surface area, surface electrodes are used for ECG measurement.
- Smaller surface area, surface electrodes are used for EEG and EMG measurement.

(i)Metal plate surface electrodes (Limb Electrodes)

- Simplest of all surface electrodes and frequently used.
- It consists of a metallic conductor in contact with the skin making use of an electrolyte gel.
- It is mostly used as limb electrodes in ECG measurement.
- It is made up of a flat metal plate that is bent into a cylindrical segment.
- There is a terminal on the cylindrical segment on its outer surface, to attach the lead wire to the electrocardiograph.

- There is also a post placed on the same side of the segment near the Centre. This post is used to connect a rubber strap to the electrode and hold it in place on the arm or leg.
- The electrode is generally made of germanium silver, nickel plated steel, nickel etc.
- There are basically two types of metal plate surface electrodes namely,
- Rectangular
- Circular
- The active surface area of a rectangular surface electrode is normally 3.5 cm* 5 cm.
- The active surface area of the circular surface electrode is 17.6cm^2 (4.75 cm – Diameter)
- The inner surface of the electrode is covered with gel or an electrolyte soaked pad is kept which will maintain the electrode contact with the skin.
- In circular metal disk electrodes the lead wire is soldered to the back surface. The connection between lead wire and electrode is protected by a layer of insulating material such as epoxy or polyvinyl chloride.
- Disk electrodes used for ECG measurements are made of silver and has an electrolytically deposited layer of AgCl on its contacting surface.
- It is also coated with electrolyte gel and placed on the patient's chest wall.
- Disk electrodes used for EMG recordings are made of stainless steel, platinum or gold plated disks.

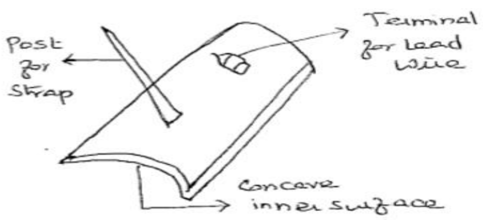


Figure 3.8 Cylindrical metal plate surface electrode

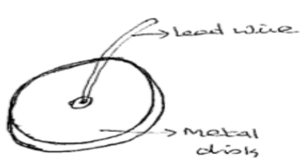


Figure 3.9 Circular metal plate surface electrode

(ii)Suction Cup electrode:

- Suction cup electrodes can be called as modified metal plate electrodes.
- These electrodes do not require straps or adhesives to hold them to a particular location.

- These electrodes are mostly used as chest lead electrodes for ECG measurement.
- They consist of a hollow metallic cylindrical electrode that makes contact with the skin at its base.
- A terminal is present on the metal cylinder for lead wire attachment.
- A rubber suction bulb is fitted to the other base of the cylinder metal electrode.
- The rubber bulb is squeezed and placed on the body, the bulb releases and applies suction against the skin, thus holding the electrode to the body.
- This electrode can be used for only short periods of time because the suction and pressure can cause irritation to the skin.
- These electrodes are generally used as ECG limb electrodes.
- These electrodes are well suited for attachment to flat surfaces of the body.

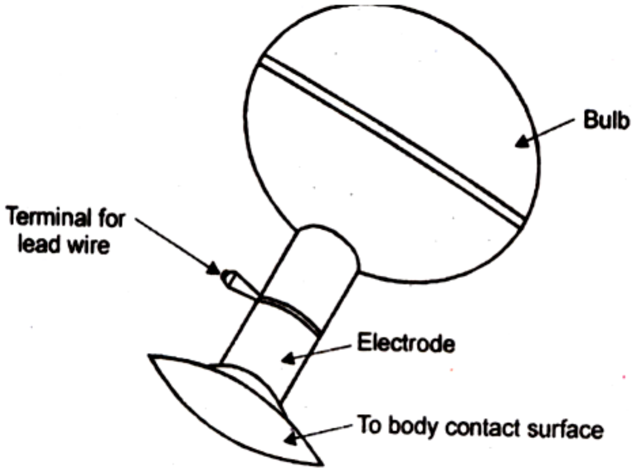


Figure 3.10 suction cup electrode

(iii)Adhesive tape electrode (Pre-gelled Disposable Electrode)

- When surface electrodes are used, the pressure applied on it across the body squeezes the gel or electrode paste out.
- Such a problem is avoided with the use of adhesive tape electrode.
- It consists of a large disk of plastic foam material with a silverplated disk on one side and silverplated snap on the other side.
- The silverplated disk serves as the electrode and may be coated with silver chloride layer.
- A layer of electrolyte gel covers the disk.
- A lead wire is snapped onto the electrode and connected to the ECG apparatus.
- The electrode side of the foam is covered with an adhesive material, which is covered with a protective foil material.

- To apply the electrode, the skin is cleaned, the protective material is removed and pressed against the patient.

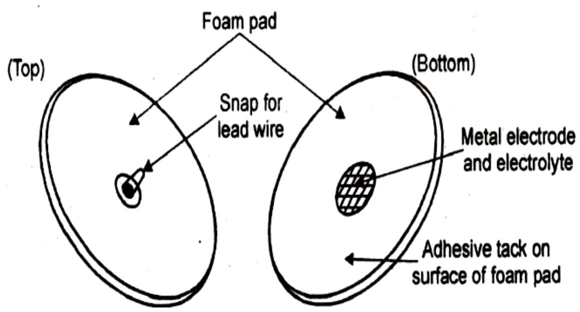


Figure 3.11 Adhesive tape electrode

iv)Multipoint electrodes:

- Multipoint electrodes contains nearly 1000 fine active contact points.
- Since the active surface area is very small, a very low resistance contact is established in these type of surface electrodes.
- These types of electrodes are used on subjects where the region of interest is covered with hair.
- These electrodes can be used under any environmental conditions.
- The multipoint electrode is a very practical electrode for ECG measurement.

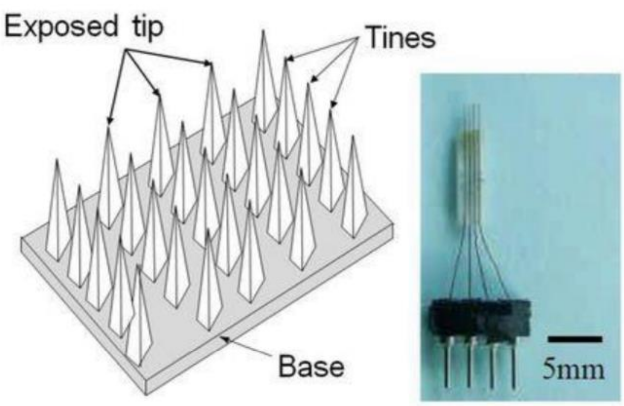


Figure 3.12 Multipoint electrode

4.Chemical Electrodes

- To measure the bioelectric potential, there is a reference electrode with constant potential and a measuring electrode, difference between them give the biopotential.
- In electrochemical measurements, it is necessary to keep one of the electrodes in the electrochemical cell at a constant potential.

3.8 Reference electrode

- The electrode which has a known potential (constant potential) is called as reference electrode.
- Reference electrodes are of two types

  (i)Primary reference electrodes

  (ii)Secondary reference electrodes

(i)Primary reference electrodes

- The reference electrode whose potential is taken as zero is called as primary reference electrode.
- E.g Standard Hydrogen Electrode (SHE)

Hydrogen Electrode

- Primary electrode to which all electrochemical measurements are referred to hydrogen electrode.
- Standard hydrogen electrode consists of a platinum wire sealed in a glass tube and carrying a platinum foil which is coated with platinum black at one end.
- The electrode is placed in a solution of an acid having 1 Molar concentration of hydrogen ions.
- Hydrogen gas at 1 atm pressure is continuously bubbled through the solution at 298 K through the side arm in such a way that the platinum foil is half immersed in Hcl while upper half is surrounded by H_2 gas.
- A redox reaction occurs when the electrode is placed in the solution.
- The oxidation or reduction takes place at the Platinum foil.
- A difference in potential occurs when hydrogen gas moves into the solution and the concentration of hydrogen concentration increases.

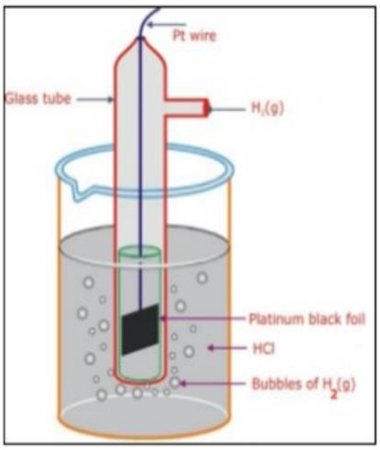


Figure 3.13 Hydrogen electrode

It is represented as Pt, H_2(latm)/H-(1M)

In a cell when the standard hydrogen electrode acts as anode, the electrode reaction can be written as

$$H_{2(g)} \longrightarrow 2H^+ + 2e^-$$

When the standard hydrogen electrode acts as cathode, the electrode reaction can be written as

$$2H^+ + 2e^- \longrightarrow H_{2(g)}$$

Based on the electrode potential obtained with reference to hydrogen, electrochemical series is obtained.

- Platinum is usually used as it readily adsorb hydrogen and is a good conductor.

Limitations

1)It is rather difficult to regulate the pressure of the H2 gas to be at exactly 1atm throughout the experiment.

2) In such a system, it is difficult to maintain the concentration of HCl at 1M.

3)Platinum foil gets easily poisoned by the impurities present in the gas and HCl

Applications

To measure pH of body fluid.

(ii)Secondary Reference Electrode

- The reference electrode whose potential is not zero but exactly known, and the electrode potential value depends on the concentration of solution in which it is dipped.
- Two types
  - ❖ Calomel electrode
  - ❖ Silver-Silver chloride electrode
- **Secondary Reference (or) Calomel Electrode**
- It consists of pure Hg at the bottom of the glass tube and covered by the paste of Mercury chloride(Calomel) and a known value of kCl.
- One side arm is used to introduce the kCl above the mercury chloride paste
- A platinum wire is sealed into a glass tube serves to make electrical contact of the electrode with the external circuit
- This act as anode or cathode depending upon the electrode which it is coupled with.
- If the electrode act as cathode

$$Hg_2cl_2 \rightleftharpoons Hg_2{}^{2+} + 2cl^-$$

$$Hg_2{}^{2+} + 2e^- \rightleftharpoons 2Hg\text{-----Reduction}$$

Hg_2cl_2 accepts electrons.

- Increase in concentration of chloride ions.

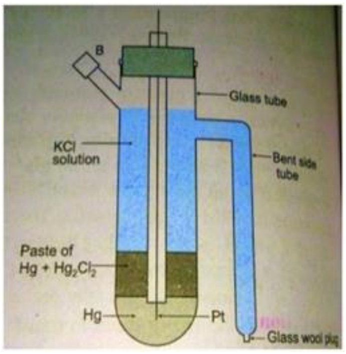


Figure 3.14 Calomel electrode

- The electrode acts as anode it would liberate electrons and Hg_2^{2+} ions into solution. These ions combine with cl- ions forming Hg_2 cl2. result is fall in concentration of chloride ions in the solution.

$$2Hg \rightleftharpoons Hg_2^{2+} + 2e^- \text{ -----Oxidation}$$
$$Hg_2^{2+} + 2cl^- \rightleftharpoons Hg_2cl2$$

- The calomel electrode can be represented as

$$Hg_{(1)} \mid Hg_2\,cl_{2(s)} | Kcl_{(xM)}$$

- Used as reference electrode in Ph measurement.
- Potential of calomel electrode depends on concentration of KCl solution.

- **Silver/Silver chloride electrode**
- The internal tube is replaced by a silver wire that is coated with silver chloride
- The wire is immersed in a pottassium chloride solution of known concentration usually of 1.0 M and saturated with silver chloride
- $Ag + Cl^- \rightleftharpoons AgCl + \text{electron } (e^-)$

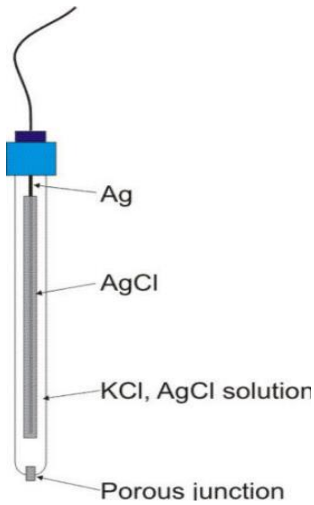


Figure 3.15 Silver/silver chloride electrode

Advantages

Easy to use, Difficult to repair

3.9 Ph Electrode

- pH of blood and otherbody fluid helps in identifying chemical balance of the body.
- ❖ pH is a measure of hydrogen ion concentration in a solution.
- ❖ pH = - log (H^+)
- ❖ Two electrodes which are involved in the measurement of pH, are

1. The glass electrode (Indicating Electrode or Sensing Electrode or Measuring Electrode)
2. The reference electrode (Calomel Electrode)

- For pH measurement silver – silver chloride electrode is used as the measuring electrode.
- ❖ The bulb provides a thin glass membrane which permits the passage of only hydrogen ions in the form of $H3O^+$.
- ❖ This glass bulb has the Ag/ AgCl electrode immersed in chloride buffer solution.
- ❖ Chloride buffer solution is nothing but KCl in 0.1M HCl.
- A calomel electrode is used as the reference electrode.
- ❖ The calomel electrode is made of a glass inner tube filled with mercurous chloride [Hg2Cl2] paste.
- ❖ This glass tube has a porous plug at the bottom.
- ❖ A platinum wire is inserted through this which is the lead wire.
- ❖ On top of the Hg2Cl2 paste an elemental mercury layer is formed.
- ❖ This whole inner glass set up is now placed in an outer bigger glass tube with the porous plug at the bottom.
- The porous plug at the bottom of the electrode assembly is used to make contact between the internal KCl electrolyte and the unknown pH test solution into which the electrode is immersed.
- ❖ The potential between this electrode and the glass measurement electrode gives the pH of the unknown solution.
- ❖ Since a salt bridge is formed between the KCl in measuring electrode – unknown test solution – KCl in reference electrode.
- ❖ It with the internal electrolyte solution, (KCl), makes contact with the sample solution via a porous glass

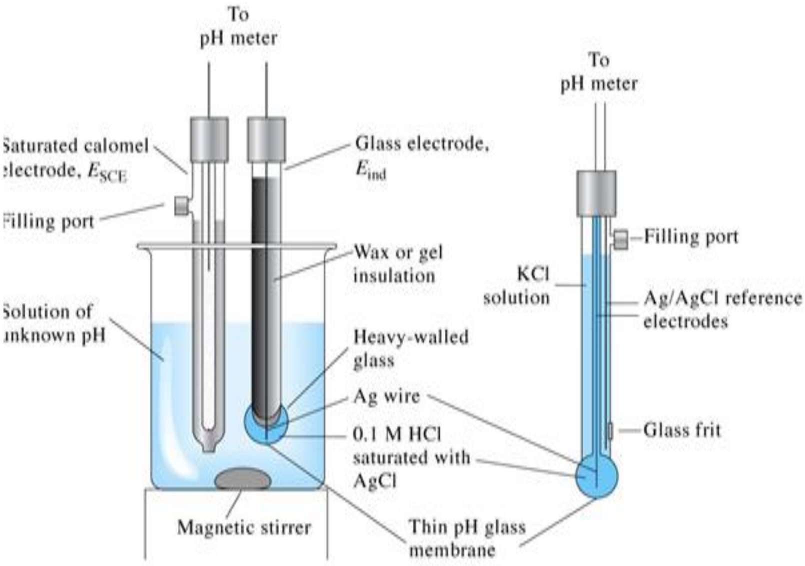


Figure 3.16 Measurement of pH

3.10 Carbondioxide electrode

- The blood pCO_2 is the partial pressure of carbondioxide of blood taken anaerobically. It is expressed in mm of Hg.
- *pCO_2 = Barometric pressure – Water vaporpressure * (% CO_2/ 100)*
- The pCO_2 electrode consists of pH sensitive glass electrode.
- The electrode is enclosed by a permeable rubber membrane.
- A thin film of water surrounds the glass electrode in between the rubber membrane and separates the membrane from the electrode.
- The whole set up is kept in the solution whose CO_2 concentration is to be found out.
- The technique is based on the fact that the dissolved CO_2 changes the pH of an aqueous solution.
- CO_2 from the solution diffuses through the rubber membrane and reaches the water film.
- The CO_2 from blood sample defuses through the membrane to form H_2CO_3, which dissociates into (H^+) and (HCO_3^-) ions.
- CO_2 from the solution diffuses through the rubber membrane and reaches the water film.
- The pH of the water film which is measured with the help of the silver/ silver chloride electrode (pH measurement electrode) gets disturbed and changes depending on the diffused CO_2.
- The resultant change in pH is thus a function of the CO_2 concentration in the sample.

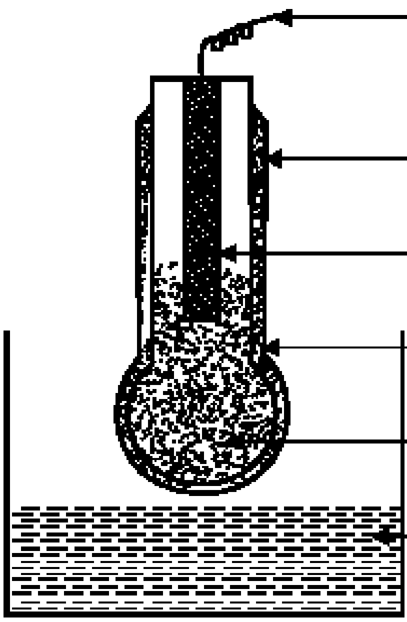


Figure 3.17 pCO2 electrode

- An alternate modified form of the electrode used for pCO2 measurement includes a thin film of an aqueous sodium bicarbonate (NaHCO3) solution instead of the water layer.
- *The* rubber membrane was also replaced by a thin Teflon membrane, which is permeable to CO2 but not to any other ions, which might alter the pH of the bicarbonate solution.
- Co2 diffuses into bicarbonate solution and causes a drop in Ph.
- Hence, the pH change is a linear function of the logarithm of the CO2 tension.
- Twice as sensitive as older version.
- Instead of Silver/ Silverchloride electrode a calomel electrode can also be used.

3.11 Oxygen electrode

- The partial pressure of oxygen in the blood or plasma indicates the extent of oxygen exchange between the lungs and the blood
- Common Po2 electrode is a clark electrode.
- The cathode is a Pt wire embedded in an insulating glass holder with end exposed into electrolyte.
- a silver/ silver chloride –anode(ref electrode)
- Electrolyte Kcl
- Permeable membrane a polypropylene membrane, only to oxygen is attached to the bottom of the cell.

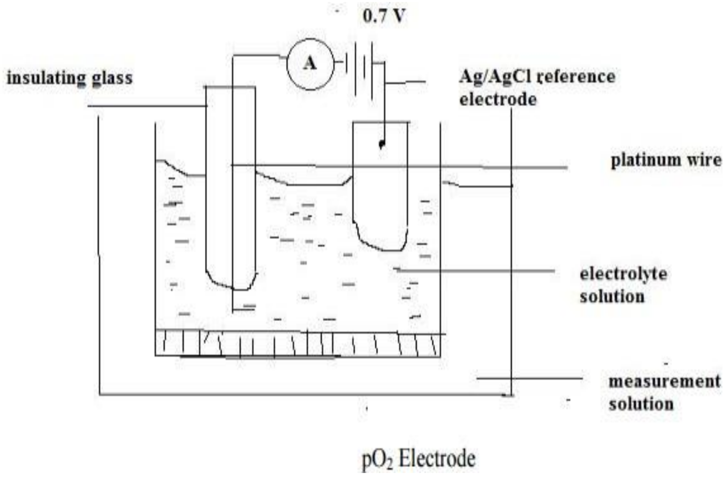


Figure 3.18 pCO2 electrode

- The entire unit is inserted into the solution under measurement. Oxygen diffuses across the polypropylene membrane into the electrolyte filling solution and is reduced at the cathode. At the anode silver is oxidized and the magnitude of the resulting current indicates the partial pressure of oxygen.
- The reactions occurring at the anode and cathode are:
- Cathode Reaction:
- $O2 + 2H2O + 4e^{-}$ à $4\ OH^{-}$
- Anode Reaction:
- $4Ag$ à $4Ag^{+} + 4e^{-}$

3.12 Electrode Skin-Interface

- Outer layer of skin is very dry and not conductive.
- An electrode paste/ gel is applied to obtain a good electric contact.
- The skin is cleaned, paste is applied and electrode is held in position with a rubber strap.
- The electrode paste decreases the impedance and also reduces the artifacts due to electrode or patients.
- Conductivity of skin is directly proportional to moisture for the skin.
- For eg: for dry skin, contact impedance-100kohm
- With electrode paste , contact impedance- 10kohm
- Transparent electrolyte gel containing Cl- is used to maintain good electric
- Contact between the electrode and the skin.
- For good conductivity, gel must have particular chloride ion concentration about (1%)

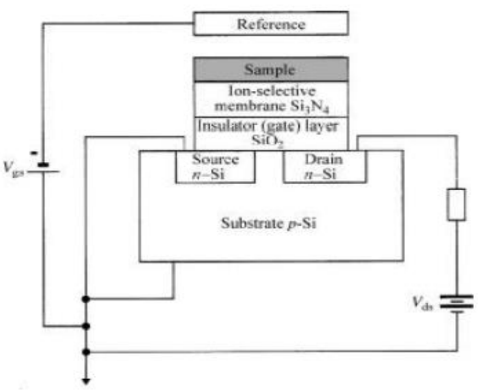
- Electrode jelly can be replaced by a conducting plastic.

3.13 Motion Artifact

- Due to movement of electrodes or patients
- When the electrode moves with respect to the electrolyte, the distribution of the double layer charge on polarizable electrode interface changes. This changes the half-cell potential temporarily.
- If a pair of electrodes is in an electrolyte and one moves with respect to the other, a potential difference appears across the electrodes known as motion artifact.
- This is a source of noise and interference in biopotential measurements.
- Motion artifact is minimal for non-polarizable electrodes.
- Can be reduced by using floating electrodes.
- Distortion is usually reduced by using large surface area electrodes.

3.14 ISFET (Ion sensitive field effect transistor)

An ISFET (Ion sensitive field effect transistor) selectively measures ion activity in an electrolyte. An ion-sensitive field-effect transistor (ISFET) is a field-effect transistor used for measuring ion concentrations in solution; when the ion concentration (such as H+,) changes, the current through the transistor will change accordingly. It is a special type of MOSFET (metal-oxide-semiconductor field-effect transistor), and shares the same basic structure, but with the metal gate replaced by an ion-sensitive membrane, electrolyte solution and reference electrode. ISFET is produced by removal of the metal gate region that is normally present on a FET. A MOSFET (metal-oxide-semiconductor field-effect transistor) is composed of two diodes separated by a gate region. The gate is a thin insulator usually silicon dioxide upon which a metallic material is deposited. Voltage applied to the gate controls the electric field in the dielectric and thus the charge on the silicon surface. High input impedance results from the gate insulator which is essential for the operation of ISFET. ISFET with the sample under measurement in contact with an ion selective membrane and a reference electrode.



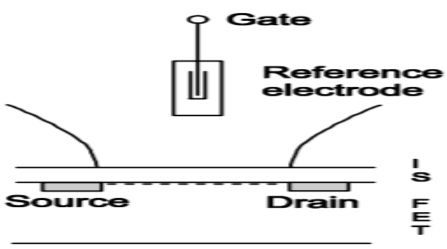


Figure 3.19 ISFET

- The potential developed across the insulator depends on the electrolyte concentration of the solution in contact with the ion selective membrane.
- The ISFET measures the potential at the gate.
- This potential is derived through an ion selective process; in which ions passing through the ion selective membrane modulate the current between the source and the drain.
- The voltage across the gate region changes and thus the field effect current flows.

Advantages

- Microminiature sensors
- Lowcost
- Small size
- Measurement speed is fast.

3.14.1 ISFET for glucose

- ISFET with an immobilized enzyme membrane has been developed, with the ion concentration change accompanying the enzymatic reaction detected by the isfet.
- Used for measuring blood glucose in diabetic patients.
- Immobilised enzyme is held between inner and outer membrane .
- Presence of glucose by changing the value of oxygen.

$$\beta\text{-D-glucose} + H_2O + O_2 \xrightarrow{\text{glucose oxidase}} \text{gluconic acid} + H_2O_2$$

- glucose oxidase, (GOD) is immobilized at the bottom of the biosensor.
- When glucose reacts with glucose oxidase, oxygen is released.
- This oxygen passes through the oxygen permeable membrane and interacts with the platinum electrode as a result of which electrons will be produced.
- Due to the electron flow in electrodes current will be created

3.14.2 ISFET for Urea

- Immobilized enzyme (gel layer) is attached to the surface of the electrode.
- Urease fixed in the acrylamide gel.
- Enzyme urease reacts with the urea and allows the ammonium ions to pass through it.
- Detected by internal electrode.
- As the pH changes the electrolyte oxide interface potential also change and due to this the threshold voltage of the ISFET changes. This variation of threshold voltage causes

the change in drain current

$$NH_2\text{-}CO\text{-}NH_2(\text{urea}) + H_2O \xrightarrow{\text{urease}} 2NH_4^+ + CO_2 + 2OH^-$$

3.15 Enzyme electrode

- Enzyme electrodes invariably refer to such devices that sense and analyze biological informations.
- Enzyme electrode is a miniature chemical transducer which functions by combining an electrochemical procedure with immobilized enzyme activity.
- Ion selective electrodes used in conjunction with immobilized enzymes can serve as the basis of electrodes that are selective for specific enzyme substrates.
- Enzymes are proteins that catalyses specific reactions to a high a degree of specificity
- The reactants are the substrates.
- Electrochemical enzyme-based biosensors are widely used because of their practical advantages, which include their
- low fabrication cost,
- simplicity of operation,
- high selectivity,
- and their ability to perform real-time detection.
- Types

  (i) Amperometric enzyme electrode

  (ii)Potentiometric enzyme electrode

  (iii)Conductimetric enzyme electrode

(i)Amperometric enzyme electrode

- Amperometric biosensors measure the electric current associated with electron flow resulting from redox reactions.
- They typically rely on an enzyme system that catalytically converts electrochemically non-active analytes into products that can be oxidized or reduced at a working electrode.
- This electrode is maintained at a specific potential with respect to a reference electrode.
- The current produced is linearly proportional to the concentration of the electroactive product, which in turn is proportional to the nonelectroactive enzyme substrate.
- The “substrate” here is any substance on which an enzyme acts.
- Enzymes typically used in amperometric biosensors are oxidases that catalyze the following class of reactions:

- Substrate + O2 → Product + H2O2
- As a result of the enzyme-catalyzed reaction, the substrate (analyte) concentration can be determined by amperometric detection of oxygen or hydrogen peroxide (H2O2).
- An example of this configuration would be an oxygen-consuming enzyme coupled to an oxygen-sensing electrode.
- The ambient oxygen concentration is then continuously monitored as it diffuses through a semi-permeable membrane and is reduced at a platinum (Pt) electrode.
- Other common configurations include the use of oxidases specific to various substrates to produce H2O2.
- During measurement, the working electrode may act as an anode or a cathode, according to the nature of the analyte.
- For example, a glucose-sensitive biosensor that uses glucose oxidase could detect the H2O2 produced by the enzymatic reaction by polarising the working electrode to a positive potential (+0.6V vs. SCE), or by polarising the working electrode to a negative potential (-0.65V vs. SCE) to monitor oxygen.

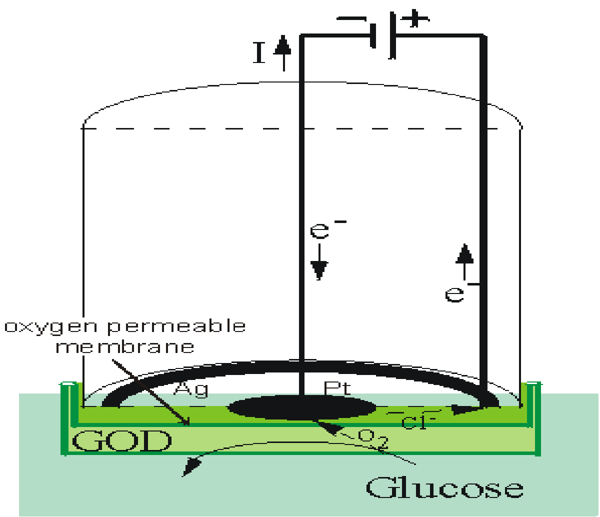
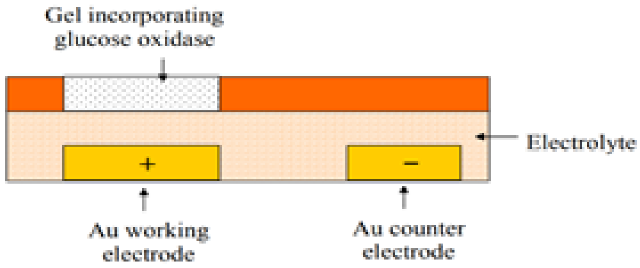


Figure 3.20 Glucose Enzyme Electrode

- A potential is applied between the central platinum cathode and the annular silver anode.
- This generates a current (I) which is carried between the electrodes by means of a saturated solution of KCl.
- This electrode compartment is separated from the biocatalyst (here shown glucose oxidase, GOD) by a thin plastic membrane, permeable only to oxygen
- Higher the glucose content higher the oxygen consumption.

- Used to measure glucose content in the blood sample.
- glucose oxidase, (GOD) is immobilized at the bottom of the biosensor.
- When glucose reacts with glucose oxidase , oxygen is released.
- This oxygen passes through the oxygen permeable membrane and interacts with the platinum electrode as a result of which electrons will be produced.
- Due to the electron flow in electrodes current will be created



$$\text{Glucose} + O_2 + H_2O \xrightarrow[\text{GOD}]{} \text{Gluconic acid} + H_2O_2$$

$$\text{Anodic: } H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$$

current passed thru working electrode

(ii)Potentiometric enzyme electrode

- Potentiometric biosensors use ion selective electrodes to determine changes in the concentration of chosen ions.
- The basic principle behind potentiometric sensor measurements is the development of a voltage related to the analyte activity (concentration) [A] in the sample through the Nernst relation:

$$E = -\frac{RT}{nF} \ln\left(\frac{a_1}{a_2}\right).$$

- where E is the potential measured,
- R is the universal gas constant,
- T is the absolute temperature, n is the valence of the ion,

and a1 and a2 are the activities of the ions on each side of the membrane.

- Potentiometric sensors will generally require a reference electrode as well as the indicator (working) electrode to be in contact with the test sample solution.

- The use of ion-selective membranes can make these sensors sensitive to various ions (e.g, hydrogen, fluorine, iodine,chlorine ions) in addition to gases such as carbon dioxide and ammonia.
- Enzyme systems,that change the concentration of any of these ions or gases, can also be incorporated into the sensor in order to be able to measure enzyme substrate concentrations, or to detect inhibitors

(e.g., heavy metal ions, insecticides) or modulators of the enzyme.

- Development of voltage related to analyte concentration in sample
- Ideally, the potential difference between the indicator and reference electrode is proportional to the logarithm of the ion activity

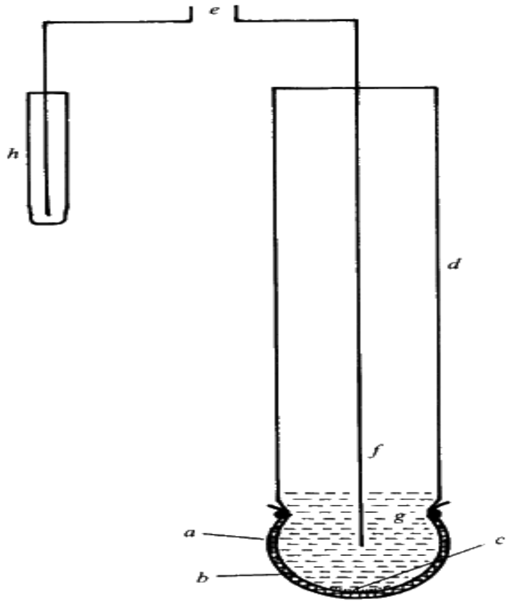


Figure 3.21 A simple potentiometric biosensor

A semi-permeable membrane (a) surrounds the biocatalyst (b) entrapped next to the active glass membrane (c) of a pH probe (d).

The electrical potential (e) is generated between the internal Ag/AgCl electrode (f) bathed in dilute HCl (g) and an external reference electrode (h).

- Consider the hydrolysis of substrate urea in the presence of enzyme urease
- A urea electrode can be prepared by immobilizing urease in a gel coating it on the surface of a cation sensitive type glass electrode (that respond to monovalent cation)
- when the electrode is dipped in the solution containing urea, the urea diffuses into the gel layer and the enzyme

$$\boxed{NH_2\text{-}CO\text{-}NH_2(\text{urea}) + H_2O \xrightarrow{\text{urease}} 2NH_4^+ + CO_2 + 2OH^-}$$

- When Co2 reacts with ph electrode, it alters the ph of the solution in the ph electrode and this causes potential difference.
- These ions diffuse to the surface of the electrode where they are sensed by cation sensitive glass to give a potential reading .
- After about 30 to 60 second , steady state reading is reached which over a certain working range is a linear function of the logarithm if the urea concentration .
- By appropriate choice of immobilized enzyme and electrode a number of substrate selective enzyme electrode have been described

(iii) Conductimetric enzyme electrode

- Measure changes in the conductivity of medium as a result of enzyme reactions that change its ionic composition.
- Conductance is directly related to the amount of ions in a medium, and since many enzyme-linked reactions result in a change in ion concentration they are suitable for conductometric biosensors.
- Enzyme reactions that produce or consume ionic species depend on the total ionic strength of the medium and changes in its conductance/capacitance can be relatively small
- Urea sensor
- Sensing enzymes can be immobilised onto the electrodes in a paste or gel form. An example of this is a urea sensor,using the enzyme urease to catalyze the hydrolysis of urea and produce ionic species (ammonium, bicarbonate and hydroxyl ions):

$$\text{urea} + 3H_2O \xrightarrow{\text{urease}} 2NH_4^+ + HCO_3^- + OH^-$$

3.16 Fiber optics

- Fiber optics (optical fibers) are long, thin strands of very pure glass about the diameter of a human hair.
- They are arranged in bundles called optical cables and used to transmit light signals over long distances.
- Core - Thin glass center of the fiber where the light travels
- Cladding - Outer optical material surrounding the core that reflects the light back into the core
- Buffer coating - Plastic coating that protects the fiber from damage and moisture
- Hundreds or thousands of these optical fibers are arranged in bundles in optical cables. The bundles are protected by the cable's outer covering, called a jacket.
- The light in a fiber-optic cable travels through the core (hallway) by constantly bouncing from the cladding (mirror-lined walls), a principle called total internal

reflection. Because the cladding does not absorb any light from the core, the light wave can travel great distances.

- **Advantages**
- Less expensive , Thinner, Less signal degradation , Low power , Digital signals , Non-flammable, Lightweight,flexible
- **Applications**
- Medical imaging - in bronchoscopes, endoscopes, laparoscopes
- Mechanical imaging - inspecting mechanical welds in pipes and engines (in airplanes, rockets, space shuttles, cars)
- Plumbing - to inspect sewer lines
- telecommunications and computer networks
- Chemical fibrosensors offer several desirable features.
- They can be made small in size.
- Multiple sensors can be introduced together, through a catheter, for intracranial or intravascular measurements.
- Because optical measurements are being made, there are no electric hazards to the patient.
- The measurements are immune to external electric interference, provided that the electronic instrumentation is properly shielded.
- No reference electrode is necessary.
- 6.high degree of flexibility ,good thermal stability, and low-cost manufacturing

3.16.1 Fiber optic pH sensor

- This pH sensor uses two single-strand optical fibres P and D .
- The distal ends of the fibres are adjacent and parallel and fit inside a cellulose dialysis hollow fibre (0.25 mm in diameter).
- The proximal end of one fibre (P) is attached to a light source.
- The other fibre (D) is used for detection.
- The cellulose hollow fibre is filled with an indicator dye, phenol red adjacent to the sealed cut ends of the optic fibre.

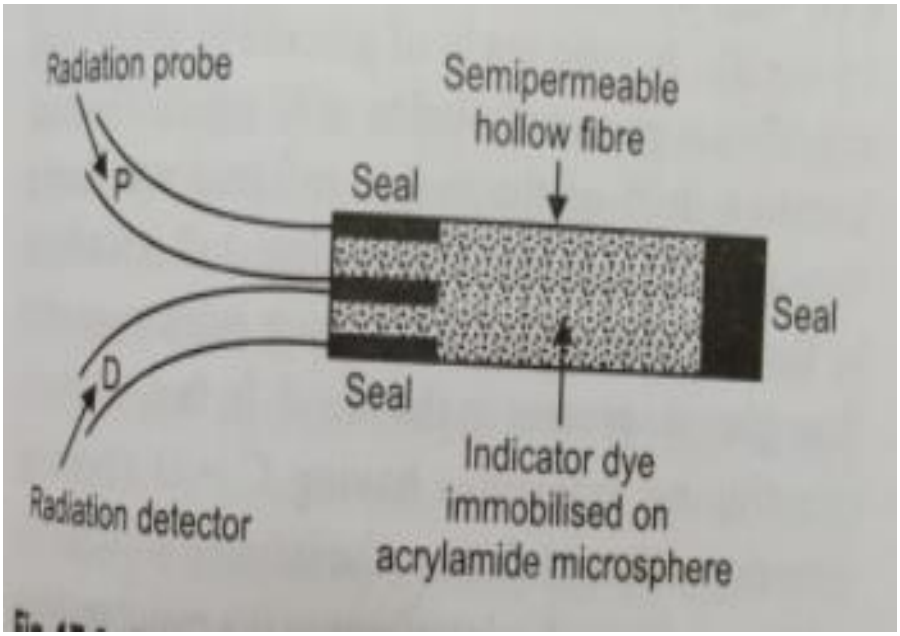


Figure 3.22 Fiber optic pH sensor

- The indicator is trapped inside the membrane by bonding it to polyacrylamide gel microspheres.
- Hydrogen ions diffusing across the cellulose fibre membrane cause the dye to change colour.
- The absorbance or colour change is quantitatively measured by the intensity of green light (550 nm) transmitted through the fibre.
- Green and red light is passed into the cell from one optical fibre.
- The green light is partially absorbed by the dye, while the red light that is not absorbed act as a reference beam.
- A separate optical fibre collects the emitted light and passes it to a photodetector for processing.

3.16.2 Optical–FiberTemperature sensors

- Temperature sensors, such as thermistor or thermocouples require metallic components and connecting wires, which disturbs the incident electromagnetic fields and may even cause localized heating spots and the temperature readings may even be erratic due to interference.
- This problem is overcome by using temperature sensors, based on fiber-optics.
- These fiber optic devices utilize externally induced changes in transmission characteristics of the optical fibers and offer typical advantages of optical fibers such as, flexibility, small dimensions and immunity from electro-magnetic interference.
- Simplest type of temperature sensors consists of a layer of liquid crystal at the end of optical fibers, giving a variation in light scattering with temperature at a particular wavelength

- A temperature sensor, which utilizes a silica-core, silicon clad fiber, with an unclad terminal portion immersed in a liquid which replace the clad.
- Temperature rise causes e reduction in refractive index in liquid, clad fiber section.
- Therefore, light travelling from the silicon clad fiber to liquid clad fiber undergoes an attenuation, which decreases by increased temperature.
- The light from an 860mm LED is coupled into the fiber.
- The light reflected backwards is sent along the same fibers and light amplitude modulation, induced by thereto sensitive cladding applied on the distal end of fiber, is detected and processed.
- One more type of temperature sensor is based on the temperature dependence of band edge absorption of infrared light in GaAs crystal.
- In this temperature measuring system light is emitted by a LED, transmitted to and from the crystal via optical fiber and measured by a photo detector.
- No metal parts are used in the temperature probe design, resulting in transparency of the probe to electromagnetic fields.

TEXT / REFERENCE BOOKS

1.John G. Webster, Medical Instrumentation Application and Design, 4th Edition, Wiley India Pvt. Ltd., New Delhi, 2015.

2.Richard S.C. Cobbold, Transducers for Biomedical Measurements: Principles and Applications, John Wiley & Sons, 2004.

3.Nandini K. Jog, Electronics in Medicine and Biomedical Instrumentation, PHI, 2nd Edition 2013.